CHAPTER -2
INTERNATIONAL INDIAN OCEAN EXPEDITION

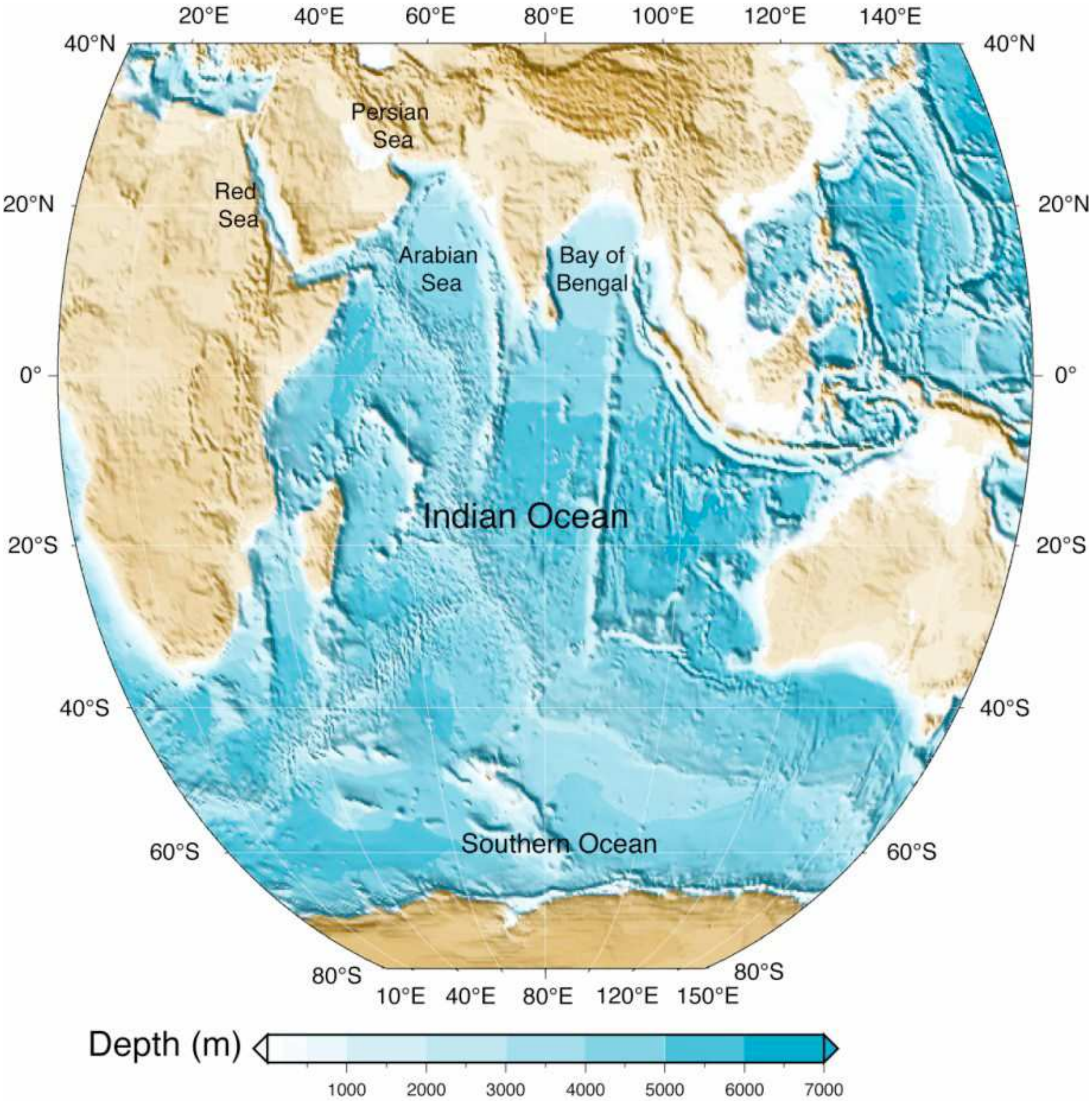


Fig.2.1.Map of the Indian Ocean with topography

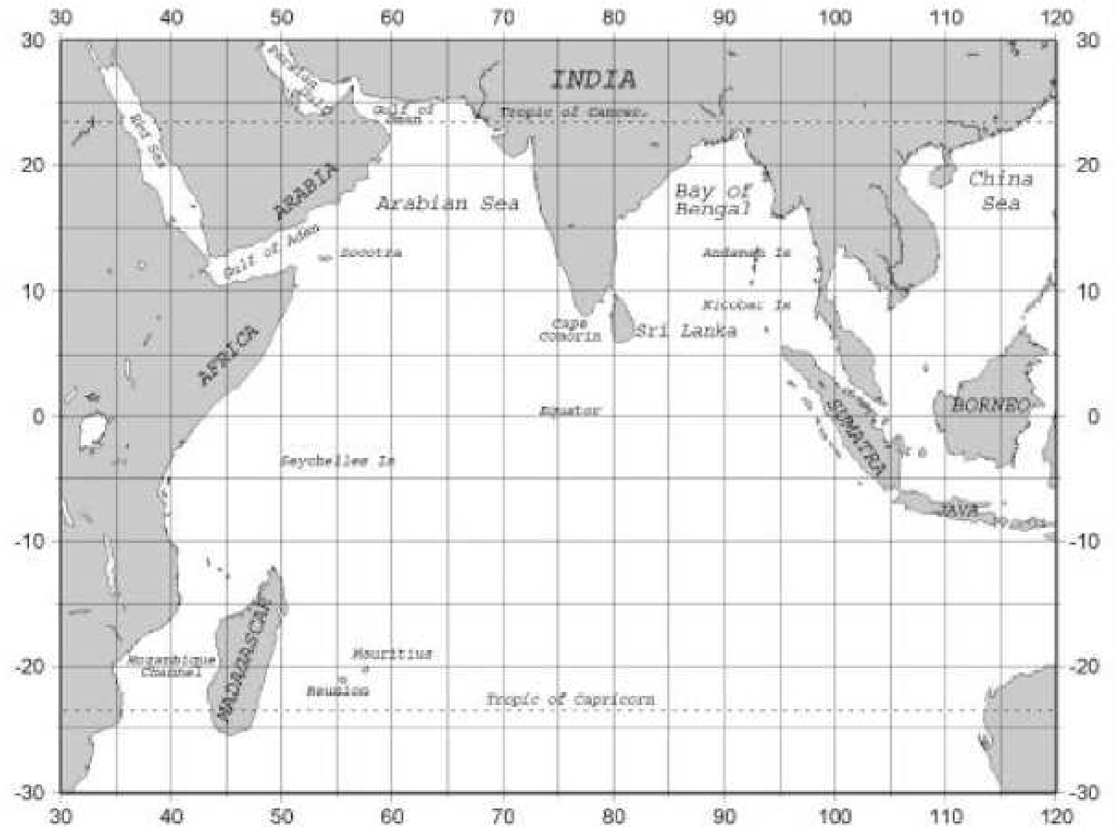


Fig.2.2. Tropical Indian Ocean

The Indian Ocean (see Fig. 2.1) is a unique environment having very special dynamics and thermodynamics due to its small size and geographical location (i.e. a tropical basin having no connection with the northern polar seas). The near-surface circulation of the North Indian Ocean (NIO) is driven by the seasonally reversing winds associated with the monsoons. The NIO in turn provides the moisture and energy to drive the summer monsoon. Hence, the ocean and the atmosphere are coupled. They work together to create the monsoon system.

The Indian Ocean is the third largest of the world's oceans and has a unique geographical setting (Fig.2.1). The Tropical Indian Ocean (TIO) (Fig.2.2) is of particular significance to the oceanographers and meteorologists as it experiences the seasonally reversing monsoon winds and is land locked on its northern side unlike the Atlantic and Pacific oceans. The Indian peninsula divides the northern part of TIO into two adjacent intra continental seas: the Arabian Sea and the Bay of Bengal. Though these two seas are located in the same latitudinal belt, they exhibit distinct oceanographic features. The Arabian Sea is connected to the warm and highly saline waters of the Persian Gulf and Red Sea, and experiences more evaporation than precipitation (except along the west coast of India during the southwest monsoon) for most of the time in a year, resulting in an upper layer of rather high saline waters. In contrast, the Bay of Bengal receives a large quantity of fresh water and sediment as river discharge and experiences more precipitation than evaporation for most of the year leading to an upper layer of less saline water. The surface waters in the Bay have such low salinity that the stratification in the upper layer is dominated by salinity gradients rather than temperature gradients. The sea surface temperature (SST) in the Bay is above 28° C and thus conductive to generation of large scale convection/precipitation for most part of the year, while in the Arabian Sea, west of about 70° E, SST is below this threshold value for most part of the year.

The International Indian Ocean Expedition (1959-1965)

The first major international effort on the Indian Ocean studies was the International Indian Ocean Expedition (IIOE), which was conducted during 1960-65 with multi-research vessel participation. The voluminous physical and chemical oceanographic data of this expedition has been compiled in the IIOE oceanographic Atlas by Wyrtki. This expedition has led to a comprehensive understanding of the steady state structure of the Indian Ocean. It also revealed several important features like the reduction of sea surface temperature in the Arabian Sea with the advancement of the south west monsoon and the variability of the Somali Current.

The genesis of the International Indian Ocean Expedition (IIOE) may be traced back to 1937, when T. W. Vaughan, in his report on the International Aspects of Oceanography, brought to the attention of the oceanographic community, the fact that very little was known about the Indian Ocean and it was time to plan and bridge this big gap in our knowledge. World War II and the subsequent turmoil interfered with such plans for almost two decades. It was only in 1957 that Lloyd Barkner, the American geophysicist who played a leading role in organizing the International Geophysical Year (IGY) and who was then President of the International Council of Scientific Unions (ICSU), requested Roger Revelle, Director of the Scripps Institution of Oceanography, to appoint a Special (later, Scientific] Committee on Oceanic Research (SCOR) so that oceanographers could play a major role in the proceedings and plans of the ICSU. Accordingly, Revelle formed a committee consisting of about 15 members; among them were G. E. R. Deacon, Director of the Institute of Oceanographic Sciences (UK), Columbus O'D. Iselin, Director of the Woods Hole Oceanographic Institution (USA), Gunther Boehrecke, Head of the German Hydrographic Office (Federal Republic of Germany), Lev Zenkevich, a Soviet marine biologist, Maurice Hill, the leader of the Marine Geophysics Group at Cambridge (UK) and N. K. Panikkar, Fisheries Development Advisor to the Government of India. At the first meeting of the SCOR, held at the Woods Hole Oceanographic Institution (WHOI) 28 August 1957, it was decided to plan an international expedition to the Indian Ocean. Roger Revelle, who presided over the meeting, appointed a Working Group under the Chairmanship of Columbus Iselin to prepare a plan for such an expedition. The members of the working group included representatives from Australia, France, Federal Republic of Germany, India, Japan, South Africa, UK, the USSR and the USA. SCOR also appointed Robert Snider as Co-ordinator, whom Revelle called 'a born expeditor'. SCOR, during its meeting at WHOI, considered three long-range problems seeking a solution by way of the proposed expedition, all of them important for the future of mankind. First, to know the Indian Ocean potential for fishery resources, since most of the countries bordering the Indian Ocean were deficient in proteins in their diet; second, to assess the role of the northern Indian Ocean in effecting the monsoonal changes, which arc vital for agricultural operations in the Indian sub-continent, but which also influence the current patterns, upwelling systems, productivity and the carbon-dioxide cycle; and third, to determine the limits to the use of the oceans for dumping human wastes, including spent nuclear fuels etc. It was also suggested that, during the first two years of the expedition, participating countries should encourage standardization of equipment and methods of analysis and data logging so that the results obtained by different ships would be comparable. SCOR also recommended that, during the third and fourth years of the expedition, as many as 16 ships should simultaneously cruise in the Indian Ocean and make a combined assault on the largest unknown area of the Earth: the deep waters of the Indian Ocean and its sea bed. With SCOR's endorsement of the Expedition, scientists from different countries began to discuss and plan their participation. There were also discordant voices, doubting whether such a large programme was feasible. There were others who very much wanted to study the Arabian Sea in particular for its reversing monsoons, the Somali upwelling and high rates of productivity. Soon there came into being a publication called the Indian Ocean Bubble at irregular intervals, and the editor invited freelance discussion on the

proposed IIOE. The first issue contained a lengthy letter from Henry Stommel, the renowned oceanographer from WHOI, recommending detailed studies of the Arabian Sea and, to quote, 'The question which we would like to resolve is how much docs the internal density structure of one of these semi-enclosed basins respond to the variations of wind stress. A clear-cut observational answer would be an interesting test of theoretical ideas about the oceanic circulation ...' Stommel also brought up the Somali current off Somalia and, again to quote, according to ship observations, the current flows toward the south during the northeast monsoon and toward the north during the southwest monsoon. It appears to be strong, intense and narrow - ideal for repeated hydrographic sections, season by season. Welander's computations indicated that this ought to be the world's most strongly oscillating current system - the difference in south and north flows amounting to about 61 million cubic metres per second.

The same issue of the Babble contained a letter from another scientist, asking 'Do you think it would be possible for some of those interested in surveying the Indian Ocean to meet in a bar or other relaxing place, during one of the less enthralling sessions of the Oceanographic Congress in New York next September, 1959?'. In the second issue of the Bubble in February 1959, R.B. Montgomery wrote a letter expressing the hope that the Indian Ocean Programme would be so designed as to aid directly the development of one or more oceanographic research centres in the underdeveloped countries bordering the Indian Ocean. This wish was fully realized in India and Pakistan, where national centers for oceanography were established after the IIOE. In the third issue of the Bubble, which appeared on 10 May 1959, a letter from Martin J. Polak was published in the same vein as above. While endorsing the proposed IIOE programme, he said, 'probably the primary need is to fill in some of the large gaps in the geographical distribution of hydrographic stations ... It seems that it should be possible to combine some of the required reconnaissance surveys with special studies of the circulation patterns. For instance, a seasonal study of the monsoon regimes in the Arabian Sea and the Bay of Bengal would serve a dual purpose: these two areas arc virtually untouched by subsurface thermometers.

How bad the Indian Ocean situation was can be grasped from a sarcastic postscript added by Montgomery to his letter in the Bubble, 'In case anyone should think of a use for them, I have a set of noon temperatures of water, air, and wet bulb made from a passenger vessel from Singapore to Suez in December 1958'. Stommel made some further comments, stating that he and Fuglister had examined bathythermographic data obtained across the equator in the Atlantic, and saw similar features to those reported for the Cromwell Current in the Pacific Ocean and if such a current exists in the Atlantic Ocean it may also exist in the Indian Ocean, and this was worth investigating. The results of the International Indian Ocean Expedition later showed that the Cromwell Current did exist in the Indian Ocean, as predicted by Stommel. Further support came from George Wust, Head of the Institute of Marine Science at the University of Kiel, Federal Republic of Germany, who submitted a plan for the survey of the Indian Ocean to SCOR. In the history of oceanography, Wust is well remembered for his classical work on board the German Research Vessel Meteor which criss-crossed the Atlantic Ocean 14 times, from 20°N to the ice edge of the Antarctic Ocean. He suggested that the Indian Ocean be investigated from about 30°N south to the Antarctic on a grid basis, stations to be occupied at 8° intervals. His plan was appended to the IIOE prospectus prepared and issued by SCOR for wide circulation and comment. The prospectus was prepared by about 4C scientists invited by SCOR, representing different disciplines in oceanography, and was finalized by a group of 3 eminent scientists, namely, Roger Revelle, of the United States, George Deacon, of the United Kingdom, and Anton Bruun, of Denmark, who had been the leader of the second Danish Galathea Deep-Sea Expedition of 1950-52 and then the first Chairman of the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Recalling those days, Behrman (1981), in his excellent book on the IIOE, quotes Revelle as remembering 'that July and August of 1960 were the most difficult months in my scientific life. After the subcommittee met in July, George Deacon, Anton Bruun and I had to put together their reports, synthesizing them into a coherent document... Nobody had studied the

Indian Ocean. This was to be an exploration in the old-fashioned sense. There were so many scientific problems and the Indian Ocean was so far away from all our institutions that no one felt that his territory was being usurped... The Indian Ocean expedition was a pioneering effort in international oceanographic planning. It was like the International Geophysical Year, but on a much bigger scale. We learned how difficult the task was. We had to accommodate conflicting interests, for this was a political operation in which people had to be persuaded.

In a letter to the fourth issue of the Indian Ocean Bubble in July 1959, LaFond wrote: 'I have been interested in the various discussions of the proposed oceanographic studies for the Indian Ocean appearing in the Indian Ocean Bubble. To me, the problem is not what to do, but rather, who in the Indian Ocean Region can be rounded up to do it? Everyone should be reminded that this is the Indian Ocean, and not the Woods Hole or Scripps Ocean. To spread the gospel and attain any lasting results, the work has to be carried on partly by the scientists of the Indian Ocean area. This does not mean just coming along for a ride, but actually give a major share in planning, analysis, and reporting. Most Asian students will be enthusiastic about the work if given the opportunity to collect data for thesis material. This opportunity and encouragement should be the primary goal for the expedition. All plans dealing with the expedition and their execution will progress very slowly in Asia due to lack of authority and the complex restrictions on travel, money exchange, imports, immigration, and numerous other necessities of the program. Thus, planning with Indian Ocean scientists for participation should start early to avoid some of the inevitable delays.

Unfortunately, it is not possible to deal directly with students. It is necessary to go down through the chain of command. The most promising approach would be to contact high-level people, such as heads of scientific organizations, naval laboratories, fisheries, or universities, explaining the proposed program. Eventually, through these contacts, it may be possible to assemble some good Indian Ocean scientists and get them started in oceanographic research in their ocean.' It was important, therefore, to involve developing countries, so that the expedition would not appear to be what Revelle called 'A club of rich countries that wanted to do oceanography'. Here, help came from the late N. K. Panikkar, an Indian scientist on SCOR, whom Revelle remembers as 'very sensible and very enthusiastic'. Shortly after the plan for the IIOE was unfolded in the prospectus issued by SCOR at its meeting in Helsinki in August 1960, Robert Snider left on a mission round the world to meet and persuade all countries interested in the expedition to contribute, plan and execute the program. In this task he got full support from the members of SCOR national committees in various countries. He particularly made it a point to meet 'political activators' and influential members of the governments and local parliaments. He also carried with him colorful charts showing the proposed cruise tracks of the IIOE and, more importantly, an IIOE emblem the use of which on letterheads and packages would facilitate customs clearance of scientific equipment, exempting them from payment of duties, etc., for all countries participating in the International Indian Ocean Expedition. In India, he approached Homi Bhaba, the eminent nuclear scientist, who in turn obtained the support of Jawaharlal Nehru, the then Prime Minister of India. The American participation in the IIOE had already been endorsed by President Eisenhower and later by President Kennedy.

In all these activities, SCOR, being a nongovernmental group, had a fairly free hand to co-ordinate the expedition program till the end of 1962, at which time, the newly formed IOC of UNESCO assumed co-ordinating responsibilities from Snider and SCOR. At the Woods Hole meeting of SCOR in August 1957, an estimate of the cost of the International Indian Ocean Expedition was projected (Table 2). Nobody seemed to have paid much attention to these cost estimates, for the simple reason that there was just no money for such a major venture, either through UNESCO or any other country. In a way, this was for the best, because individual countries had to fend for themselves to obtain the necessary funds from their own governmental agencies. Recognizing the importance of the Expedition, and the fact that economic conditions were improving worldwide, many countries found funds and support from their governments for

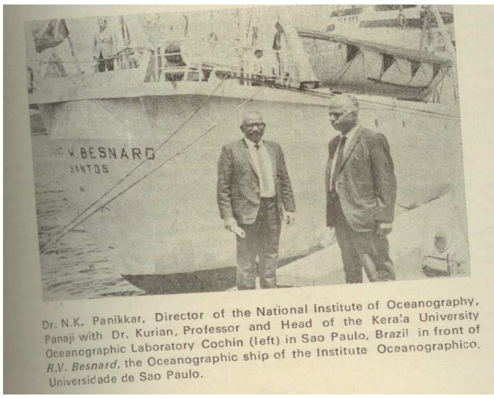
their participation in the IIOE. At the Helsinki meeting of SCOR in August 1960, plans for the IIOE and general guidelines were issued. The SCOR working groups on the Indian Ocean gave some directions to the scientific programmes. The panel for physical oceanography, meteorology and chemistry recommended some areas for intense study: the Arabian Sea in summer and winter and the waters northwest of Australia; the Red Sea and the Persian Gulf for their heat budget and, similarly, the southern part of the Bay of Bengal. Emphasis was laid on correlating weather charts with oceanographic conditions wherever possible. In chemistry, it was urged that all participating ships undertake a minimum common program, such as the collection and analysis of water samples from standard depths for estimating dissolved oxygen and nutrients at each station. The panel on geology requested that all ships carry precision echo sounders and continuously run them to record the water depth and to share such information with all other participating ships. Geomagnetic and gravimetric studies were also planned. In the biology program, it was recommended that plankton samples be collected at all stations using an Indian Ocean Standard Net, designed by Currie, and make a vertical haul from 200m depth to the surface. Also, phytoplankton samples and productivity measurements should be taken wherever possible, and more particularly along the meridians 62°, 78° and 95° in the north-south direction. Another recommendation was to establish a sorting centre for zooplankton in India, where all the zooplankton samples could be sorted group-wise and then distributed to specialists. All the participating ships were requested to send the plankton samples to the proposed sorting centre.

Another very important program endorsed and executed by SCOR and UNESCO related to the inter-calibration of equipment and standardization of analytical procedures. Accordingly, three such tests were conducted, the first of which was organized in September 1960, at Honolulu, on board the Australian ship Gascoyne, the Soviet vessel Vityaz and at the laboratories of the University of Hawaii. The second test was held off Freemantle, Australia, again on board the Vityaz. And finally, a third series of chemical tests was organized on board the British ship Discovery in 1964. Against this background, an exciting drama to unfold the scientific secrets was played on the vast stage of the Indian Ocean. In view of its strategic location, India played a significant role in the overall operations and co-ordination of the IIOE, as well as being an active participant.

The Indian response to the IIOE

A person in the right place at the right time was N. K. Panikkar in India. As already mentioned earlier in this chapter, Panikkar held a very influential position as Fisheries Development Advisor in the Ministry of Food and Agriculture, in Delhi. He also represented India on SCOR. Besides, Panikkar knew, perhaps better than anyone in India, the marine research capabilities that the country could muster for taking part in the IIOE. Having participated in the SCORUNESCO meetings in Paris and Helsinki in 1960, Panikkar decided to act and, on his advice, the Government in Delhi appointed an Indian National Committee on Oceanic Research (1NCOR) with the following terms of reference:

- to draw up a co-ordinated plan for India's participation in the IIOE;
- to advise on the allocation of a program between governmental departments, research organizations, universities and other institutions;
- to consider and approve detailed plans for research in the several scientific disciplines related to India's participation and to recommend financial grants;
- to further and co-ordinate research programmes;
- to advise the Government generally on all matters connected with India's participation in the Expedition.



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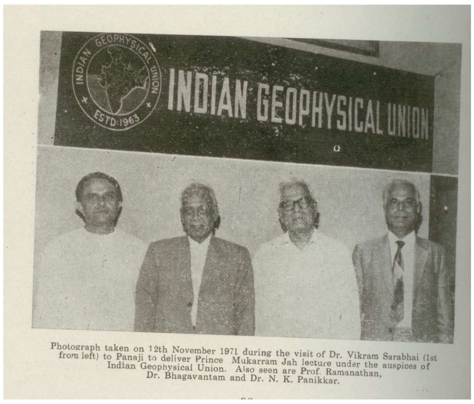


(b)

Photo: a)L to R: Prof.C.V.Kurien, Founder Director, School of Marine Sciences, Cochin University of Science & Technology, Dr.N.K.Panikar, Founder Director of NIO; b) Dr.Vikram Sarabhai, Founder Director of ISRO, Prof.Suri Bhagavantham,Famous Physicist, Prof.R.Ramanadham, Founder Head & Professor of Department of Meteorology & Oceanography, Andhra University, & Dr.N.K.Panikar

In the light of these terms of reference, INCOR, besides being responsible for India's participation in the IIOE, also became the focus for all developments and research projects connected with oceanographic research in the country. The Committee and its working groups included almost all the important scientists representing various Indian institutions concerned with different branches of oceanography. The results of the Committee's deliberations led directly to the establishment of an Indian Ocean Expedition Directorate as a department of the Council of Scientific and Industrial Research, and to the allocation of sufficient funds and staff to ensure the full participation of India in this Expedition. The subsequent establishment of the International Meteorological Centre at Colaba (Bombay) and the Indian Ocean Biological Centre at Cochin (Kochi) is well known to marine scientists the world over. The Expedition sought to explore in detail the oceanography of the Indian Ocean and to make the area as well known as the Atlantic and the Pacific. It was also fashionable for all who ever spoke on the program of IIOE to draw attention to the enormous population increase of India and neighboring countries and the inadequacy of food and protein supply for the undernourished people and to plead fervently for the exploration and exploitation of the food resources of the sea. If the speaker was a marine meteorologist, he would say how interesting are the reversing monsoons and how unpredictable or unreliable they are for Indian agriculturists. A geophysicist would stress the possibility of locating oil resources in the shelf areas off India. In this way, all sought to justify the many cruises, ships and nations participating in the joint enterprise of the IIOE. India's response to the call of the IIOE, as that of other countries in the region, was positive. India's exploitation of fishery resources has been growing every year and it was reasonable to expect that, given more vessels and men, it should be possible to double the gross tonnage of fish landed on India's coasts. The most interesting aspect of the problem, however, was the fact that 67-75% of marine fish landed annually in India came from the west coast. This was pointed out by Panikkar and Jayaraman (1956) at the 8th Pacific Science Congress, and the picture remains the same even today. The reason for the apparent scarcity of fishery resources off the east coast of India and the rest of the Bay of Bengal should be urgently investigated and considered quite separately from the problem of whether we are fully exploiting the available fishery resources off the west coast.

Although, in recent years, mechanization of fishing vessels has increased, the fact remains that fishing is done mostly in near shore waters while the vast shelf off the west coast remains totally unexploited. For example, off the Bombay and Gujarat coasts, the shelf extends out for nearly 200 miles and, but for a few vessels of the deep-sea section of the Food and Agriculture Ministry, no large-scale commercial trawlers are commissioned to fish these vast areas. Regular mapping of coastal areas rich in fishery resources was one of India's immediate requirements. Next, we may consider the mineral resources of the sea. India lacks natural deposits of fertilizer salts and rich deposits of fossil fuel. One of the ingenious suggestions was that the possibility of extracting nutrient salts, such as phosphates and nitrates, from the vast quantities of marine sediments dumped by the great river systems into the Bay of Bengal and the Arabian Sea should be considered. The possible accumulation of oil under the shelf (offshore areas), particularly off Cambay, was also considered suitable for investigation, particularly since the nearby area of Ankaleswar had yielded exploitable deposits of gas and oil. Again, the mapping of coastal currents and the bathymetry of near-shore areas, and their importance for coastal navigation, defence, harbour construction, and so on, cannot be minimized. With the increase in industries and the number of nuclear reactors, the question of pollution and waste disposal takes on added significance. Our knowledge of coastal bathymetry and bottom topography was inadequate and the physical oceanography of the coastal waters was almost unknown. The use of modern instruments was essential. Finally, there was the study of the monsoons. Two problems were involved: first, how does the reversal of the monsoons affect the oceanic circulation in the northern Indian Ocean, and secondly, how may the onset and intensity of the southwest monsoon be predicted. This second problem was of great agricultural importance since most of the farmers in India depend on monsoon rains for the cultivation of summer crops (kharif).

These were some of the problems in which India was interested at the time of launching of the IIOE (Rao, 1967). Quite rightly, therefore, the planners of the Indian Program concentrated their efforts in these directions and constrained their cruises and observations so as to obtain substantial information on the coastal areas in the Arabian Sea and the Bay of Bengal. With the inauguration of the 1st Scientific Cruise of INS Kistna on 9 October 1962, by Professor Humayun Kabir, Minister for Scientific Research and Cultural Affairs, the Indian Program of Work during the IIOE was officially launched. Besides INS Kistna, the Indian Program included scientific cruises by RV Varuna, of the Indo-Norwegian project, RV Conch, of the University of Kerala, and FV Bangada, an exploratory fishing vessel of the Ministry of Food and Agriculture, Government of India. All the cruise tracks and program of work were co-ordinated so that a complete coverage of important coastal areas in the Bay of Bengal and the Arabian Sea was affected. The participation and program of the INS Kistna in the IIOE are unique in many respects. The Indian Navy should be congratulated for placing the frigate at the disposal of the Indian National Committee on Ocean Research solely for oceanographical work. This was a most welcome development for the future of ocean sciences in India since, by this gesture of cooperation; the Indian Navy’s full support of IIOE was assured. Commencing in October 1962, INS Kistna completed 28 scientific cruises and, had it not been for the unfortunate Indo-Pakistan conflict in the middle of 1965, she would have successfully accomplished the rest of the cruises planned for the autumn of 1965. The vast amount of data collected by INS Kistna were later analysed at the data and planning division of the National Institute of Oceanography. Meanwhile, the International Meteorological Centre (IMC) at Colaba, Bombay, functioned from 1 January 1962, with Prof. C. S. Ramage of the University of Hawaii as Director. This Centre was financed by the Council of Scientific and Industrial Research and was manned by the Indian Meteorological Department. The United Nations Special Fund provided an IBM 1620 electronic computer for data processing. The US National Science Foundation gave liberal assistance in the form of equipment and other services. The extended Indian Ocean chart in use at IMC covers the whole of the Indian Ocean plus adjacent areas. Reception of about 75 daily radio teletype broadcasts from Canberra, Nairobi, Singapore and Pretoria provided the bulk of the southern

hemisphere coverage. Data exchanged with Tokyo and Moscow and some 40 radio teletype/ carrier-wave broadcasts received from Karachi, Aden, Colombo, Jakarta and Saigon, supplemented by collections at the meteorological communication centre, formed the coverage of the northern hemisphere. Ships' reports obtained over radio teletype circuits from Mauritius by the Indian Navy added to the coverage of the southern Indian Ocean. On a typical day the total coverage amounted to: Surface reports - 1155; Ships - 384; Upper air - 429. Aircraft reported from long-distance international flights on three or four air routes. At the IMC, synoptic charts were prepared for two principal times - 00 and 12 hours Greenwich Mean Time - for surface and standard isobaric levels; namely, 50, 100, 200, 300, 500 and 700mb. Back plotting was also done after reception of additional information/ data from other centers. During the IIOE, perhaps the most important observations on the monsoons were carried out by specially instrumented research aircraft of the US Weather Bureau Research Flight Facility and by the Woods Hole Oceanographic Institution. In addition, an automatic weather station was anchored in the Bay of Bengal half-way between Madras and the Andamans in April 1964 but this was soon lost. An Automatic Picture Transmission (APT) receiving equipment on loan from the US National Science Foundation was installed at IMC in December 1963, and this picked up pictures of cloud cover from Tiros VII and Nimbus meteorological satellites during their orbits over the Indian subcontinent. It is too early to say that the IMC has solved the problem of the development of the monsoon or is able to predict the arrival of the monsoon accurately, but it has accumulated a vast quantity of information and the preliminary analysis of the data has improved our knowledge of the circulation pattern of the monsoon winds. In fact, for the first time, meteorologists in India were able to get data from over the oceans for their studies and have come to realize that the weather pattern of the Indian sub-continent is greatly influenced by conditions in the sea.

The Indian Ocean Biological Centre (IOBC) (1962-66):

The establishment of the Indian Ocean Biological Centre (IOBC) at Ernakulam (Cochin) marks a very important milestone in the history of marine biology in India. The Centre was established by the Council of Scientific and Industrial Research in co-operation with UNESCO. The main considerations which led to the selection of India for the location of the Centre were:

1. geographical location of India at whose ports many of the ships participating in the expedition were likely to call;
2. the very considerable interest in biological and taxonomic studies in India at scientific and university institutions;
3. the availability of a large number of trained biologists who could take on the work;
4. the advantage of a centre of this type in South Asia which would stimulate marine biological studies in the Asian region.

The principal functions of the Centre were:

a) maintenance of a named reference collection of Indian Ocean material and duplication of it for laboratories throughout the world;
b) sorting zooplankton samples taken by standard methods
c) examination of the sorted standard material or sending it to specialists throughout the world;
d) sorting of zooplankton samples at the request and expense of participating laboratories;
e) training.

The development of this Centre in India has provided a unique opportunity for the training of biologists from India and other countries in the region.

The US IIOE Program in biology:

Woods Hole is a picturesque village located on Cape Cod in the State of Massachusetts in the United States. Geomorphologically, Cape Cod is like a hooked finger projecting from the northeast American coast and appears to beckon people from other countries, which is a fact if one looks at the number of foreign visitors during the summer months at the famous Woods Hole Oceanographic Institution (WHOI) and the Marine Biological Laboratory (MBL). As already indicated, it was at WHOI that a decision to plan the IIOE was made in August 1957 by a group of eminent oceanographers who met under the chairmanship of Roger Revelle. The US National Committee acquired the Presidential Yacht Williamsburg for conversion into an oceanographic vessel (the ship was 243 feet (73m) long and displaced 1700 tons) and was renamed the Anton Bruun, after the famous Danish scientist who led the second Galathea Deep-Sea Expedition round the world in 1950-52. Also, as the first Chairman of the Intergovernmental Oceanographic Commission of UNESCO, at that time, he influenced the UN bodies concerned and the Member States to support the proposed International Indian Ocean Expedition. The National Science Foundation named John Ryther, a renowned scientist at WHOI, as Director, and Edward Chin, as Associate Director, of the US Program in Biology in the IIOE and gave them a free hand to organize the Anton Bruun cruises in the Indian Ocean. Ryther had a good understanding of the problems in biology the Expedition was seeking to solve. Behrman (1981) quotes Ryther's writing in 1963 that 'for the systematics, the Indian Ocean represents a world of which only tantalizing glimpses have been obtained. A few fortunate individuals have taken part in expeditions to some of the more remote, exotic island groups (the Seychelles, Maldives, Laccadives, Comores and Chagos) and have brought back a wealth of new material. Just enough is known of the flora and fauna of these areas to whet the appetite of the taxonomist with the desire to make a thorough and exhaustive study of the entire region ... For the ecologist, there are reports of many fascinating phenomena of unknown nature and origin. Vast fish mortalities in the central Arabian Sea are perhaps produced by the overturn of water from mid-depths reportedly devoid of oxygen and laden with hydrogen sulphide. The central Bay of Bengal may at times have similar properties. Are these anoxic layers related to the biological productivity of the overlying surface waters? Do they reflect stagnation implying lack of vertical or horizontal circulation for long periods of time? Notorious outbreaks of discolored water, sometimes also producing mass mortalities of marine life, are frequently reported along the coasts of India and Africa. Are these "blooms" of dinoflagellates similar to the causative agent of the Florida red tide? Are they the result of fertilization of the coastal waters from upwelling processes...?

Huge meadows of blue-green algae extending for many hundreds of square miles are known to occur in the Arabian Sea. What makes these plants grow in this particular region? Where do they get their nutrients? How does their presence affect other forms of marine life? These are just a few of the problems, probably unique in the Indian Ocean, which will require a combination of physical, chemical and biological information to answer. The Anton Bruun had a crew of 30 and accommodation for 28 scientists. Of these, 8 staff scientists were responsible for the basic programmes such as casting of water bottles, BT lowerings, plankton collections, primary-production determinations, meteorological observations, depth soundings, etc. In early 1962, Ryther held a planning conference in New York and, because of his previous work in the Bay of Bengal and good contacts with Indian scientists, asked Eugene LaFond to head the first cruise of the Anton Bruun and to develop a program for the Bay of Bengal and Andaman Sea areas. Since the Andhra University oceanographers had established the time and space variables on the western side of the Bay of Bengal, LaFond wanted to establish the same variables on the opposite side of the Bay. For example, when upwelling occurs off Waltair, would upwelling exist on the other side or would we find sinking? Would the immense dilution due to river discharges

extend as far down the east side as it does in the west? There were other questions dealing with the monsoon circulation gyres, such as: are the currents in the Bay form one large eddy or are they broken up into smaller gyres? To answer these questions, a pattern of stations was laid out along a track crisscrossing the Andaman Sea, and the eastern, northern and western parts of the Bay of Bengal. Prior to the beginning of the cruise, Panikkar asked the LaFonds to visit Indian marine science centres, give lectures, and explain the IIOE programme and, especially, the objective of the US Programme in Biology and the Anton Bruun cruises (Table 1.7). A number of Indian scientists were invited to participate in the cruises. The LaFonds visited and lectured at:

1. Bombay Academy of Sciences, in Bombay
2. Taraporevala Marine Biological Research Station, in Bombay
3. Osmania University, in Hyderabad
4. Andhra University, in Waltair
5. Navy Physical Laboratory, in Cochin
6. Oceanographic Research Wing of National Geophysical Research Institute, in Cochin
7. Maharaja's College, in Ernakulam
8. Kerala University, in Trivandrum
9. Central Marine Fisheries Research Institute, in Mandapam
10. Annamalai University, in Chidambaram
11. Maharaja Sayajirao University, in Baroda
12. Gujarat University, in Ahmedabad
13. Physical Research Laboratory, in Ahmedabad
14. Delhi University, in New Delhi

These lectures and discussions informed the Indian scientific community of the oceanographic programmes about to take place in the Indian Ocean, and the members of this community were invited to participate in the scientific cruises. The Anton Bruun arrived in Bombay in early March 1963 after occupying a series of stations in the Arabian Sea. She soon refueled and departed on 12 March on the first of 9 cruises (see Table 1.7) with all scientific billets filled.

Table.2.1. Anton Bruun cruises in the Indian Ocean during the IIOE

Cruise No	Date	Area covered
A	24.2.1963-4.31963	Gulf of Aden to Bombay
1.	12.3.63 – 10.5.63	Bay of Bengal
2.	22.5.63 – 23.7.63	Along 70 ^{o}Eand 80 ^{o} E
3.	8.8.63-20.9.63	Along 60 ^{o} E
4.	25.9.63-10.12.63	Western Arabian Sea
5.	26.1.64-4.5.64	Along 55 ^{o} E
6.	16.5.64-16.7.64	Along 65 ^{o} E
7.	29.7.64-10.9.64	East African Coast
8.	25.9.64-9.11.64	East African Coast
9.	18.11.64-28.12.64	Somalia and Red Sea

The initial program consisted of taking underway BT observations from Bombay across the southern Bay of Bengal to the Andaman Sea. In the Andaman Sea, the ship stopped for full-fledged oceanographic stations. The normal procedure in occupying a station was to make the following measurements and collections:

• hydrographic cast using Nansen bottles;
• 200m haul with the IIOE plankton net;

• phytoplankton trawl;
• deep-water fish trawl;
• vertical series of water samples for primary production;
• meteorological observations;
• bathythermograph lowering to 900 feet (275m);
• coring and dredging of the sea floor;

The Indian scientists who participated in the first leg were:

- C. Poornachandra Rao (meteorologist), International Meteorological Centre, Bombay
- S.P. Anand (chemist), Indian Research and Development Centre, New Delhi
- K. Balasubrahmanyan (marine biologist), Annamalai University, Marine Biological
- Station, Porto Novo
- V. Chalapati Rao (marine biologist), Andhra University, Waltair
- R. Varadarajulu (meteorologist), Andhra University, Waltair
- Others who joined the first Anton Bruun cruise on one or more later legs were:
- P. W. Backar (photographer), Ministry of Information and Broadcasting, Bombay
- P. Chandramohan (marine biologist), Andhra University, Waltair
- C. M. Gupta (marine geologist), University of Baroda, Baroda
- R. M. Kidwai (marine geologist), Andhra University, Waltair
- G. R. Lakshmana Rao (physical oceanographer), Andhra University
- G. H. Madhusudana Rao (marine geologist), Andhra University
- K. V. Nair (marine planktonologist), Indian Ocean Biological Centre, Ernakulam
- N. K. Panikkar (marine fisheries biologist), Council of Scientific and Industrial Research, New Delhi
- B. Ramireddi (meteorologist), Andhra University, Waltair
- M. Sakthivel (marine planktonologist), Indian Ocean Biological Centre, Ernakulam
- V. N. Sankaranarayan (marine chemist), Indian Ocean Biological Centre, Ernakulam
- T. S. S. Rao (marine biologist), Scientific Liaison Office, Bombay
- R. V. Unnithan (marine biologist), Indian Ocean Biological Centre, Ernakulam
- V. V. R. Varadachari (physical oceanographcr and marine meteorologist), Andhra
- University, Waltair
- S. Varma (photographer), Ministry of Information and Broadcasting, Madras
- B. Wagh (marine planktonologist), Institute of Science, Bombay
- P. K. Das (physical oceanographer), National Geophysical Research Institute, Cochin
- K. Krishnamurty (marine zoologist), Annamalai University, Marine Biological Station, Porto Novo
- In addition to the Indian oceanographers and the eight staff scientists, there were two Thai scientists:
- Thumnoon Supanich (marine biologist), Chulalongkorn University, Bangkok.
- Mahn Bhovichitra (fisheries biologist), Chulalongkorn University, Bangkok.

Needless to say, enormous quantities of oceanographic data were obtained from the network of stations throughout the Andaman Sea and Bay of Bengal. In this connection, it may be stated that very little information was available on the responses of other countries in the Indian Ocean area, once the IIOE was over. One could infer from later publications, that Pakistan and some Gulf States had established marine research institutions. For its part, India went ahead to advance marine research in a big way.

The benefits of the IIOE to India:

The IIOE achieved for itself the distinction of being one of the best examples of co-operation between many nations from East and West. Indian scientists visited many neighboring countries and the Indian ship INS Kistna visited Singapore. India hosted the scientists from many nations, resulting in deep and abiding friendships. Many of the participating foreign research ships, as the RV Anton Bruun, RV Argo and RV Horizon (USA), the RV Vityaz (USSR) and the RRS Discovery (UK) provided facilities for ship-board training and research for many Indian scientists. The expedition also provided opportunities for organizing seminars in which many young scientists from different parts of the country and senior scientists from abroad participated. An All-India Seminar on Marine Science was held in Waltair, 26-27 April 1963, sponsored by the Andhra University, Waltair, the Indian National Committee on Ocean Research, the US Program in Biology and the US Information Service, to present results from the first Anton Bruun cruise. It was well attended and was a great success. In July 1965, an International Symposium on the Meteorological Results of IIOE was held in Mumbai and this was attended by a large number of foreign and Indian participants.

As a finale to all this activity, a training program was organized (sponsored by UNESCO & C.S.I.R) at the postgraduate level to train junior scientists to carry out ocean research during January-March 1966 at Mumbai. While the training program marked the end of IIOE activities, it also saw the birth of the National Institute of Oceanography (NIO) of India with the Headquarters at Goa. The Indian Government approved the establishment of this institute as one of the national laboratories under the CSIR and appointed Dr. N.K. Panikkar, Director of the Indian Program under the IIOE, as Director of the new institute. The Indian Ocean Biological Centre at Kochi, has become the Regional center of the National Institute of Oceanography. Later two more regional centers at Mumbai and Visakhapatnam were also added.

The Principal Atlases resulting from the International Indian Ocean Expedition are:

1. Oceanographic Atlas of the International Indian Ocean Expedition. Wyrtki, K. (1971). National Science Foundation, Washington DC, USA.
2. Meteorological Atlas of the International Indian Ocean Expedition. National Science Foundation, Washington DC, USA. Ramage, C.S., F.R. Miller and C. Jcfferics (1972).
3. The surface climate of 1963 and 1964. Ramagc, C.S. and C.V.R. Raman (1972).
4. Geological-geophysical Atlas of the Indian Ocean. Udintsev, G. B., editor (1975). Academy of Sciences, Moscow.
5. Phytoplankton Production Atlas of the International Indian Ocean Expedition. Krey, J. and B. Babenard (1976). Institut fur Meereskunde, Kiel.
6. International Indian Ocean Expedition Plankton Atlas. Panikkar, N.K., editor (1968-1973).

- 1(1): Maps on total zooplankton biomass in the Arabian Sea and the Bay of Bengal (1968).
- 1(2): Maps on total zooplankton biomass in the Indian Ocean (1968).
- 2(1): Distribution of copepod and decapod larvae in the Indian Ocean (1970).
- 2(2): Distribution ot fish eggs and larvae in the Indian Ocean (1970).
- 3(1): Distribution of Crustacea (Cladocera, O.stracoda, Cirripedia, Mysidacea, Cumacca, Isopoda,
- Amphipoda, Kuphausiacea, Stomatopoda) and Insecta (Halobatida) in the Indian Ocean (1972).
- 3(2): Distribution ot planktonic inollusca of the Indian Ocean (1972).

- 4(1 &2): Distribution of Platyhelminthes, Tomopteridae and other pelagic Polychatta, Trochophores and Sipunculida ot the Indian Ocean (1973). Distribution of Actinotrocha, brachiopod larvae, Chaetognatha, Copelata, Pyrosoma, salps and doliotids and Amphioxus of the Indian Ocean (1973).
- 5(1 &2): Indian Ocean Biological Centre, National Institute of Oceanography, Council of Scientific and Industrial Research, New Delhi.

The main results of the IIOE:

The IIOE ended officially in 1965. More than 40 oceanographic research vessels belonging to 13 countries surveyed the Indian Ocean and collected useful data in almost all disciplines in the marine sciences, except perhaps in fishery research and marine microbiology.
Since the completion of the expedition, hundreds of papers have been published and some of them reprinted and included in the 8 volumes of collected reprints of the International Indian Ocean Expedition published by UNESCO. This apart, a set of atlases was published which is unique for the Indian Ocean (Table 2). The introduction of computers for data logging and analysis made a world of difference in the handling of large amounts of data collected during the various cruises. Many countries along with NIO established national oceanographic data centres for storage and dissemination of information. Two World Data Centres were also created, one in Washington, DC, and another in Moscow. Moreover, sorting centres for handling fauna and flora, including plankton, came into existence in Cochin (Indian Ocean Biological Centre), in Tunis (The Mediterranean Sorting Centre), and the National Oceanographic Data Centre at the Smithsonian Institution in Washington, DC. Some time later, a sorting centre was also started in Mexico. For biology specialists, the sorting centres were of immense help, since the drudgery of mechanical sorting of animals and plants was done elsewhere, so that the biologists could concentrate on their specialized work. Perhaps the most important thing was that oceanography became an eligible science for support and funding by the governments, particularly those of developing countries, and the interest shown in the IIOE by developed countries by their extended participation in an area so remote from their home, triggered a kind of paradigm for the developing countries. The benefits to coastal countries in the Indian Ocean region include the training of their scientists aboard research vessels like the Discovery (UK), the Meteor (Germany), the Atlantis and the Anton Bruun (USA).

This apart, oceanographic and marine biological research institutes were either newly started or the existing ones were strengthened. The oceanographic institutes established at Karachi, Pakistan, and Goa, India, the marine stations at Pukhet in Thailand and Nosy-be in Madagascar, and the East African Marine Fisheries Research Institute in Zanzibar are some of the examples. What was even more important was the mingling of scientists with different backgrounds, both in scientific status and culture, for the common cause of Indian Ocean exploration; they got to know each other and continued their contacts for many more years after the Expedition. From the technical point of view, the six years of the IIOE (1959-65) marked a watershed in the state of the art in oceanographic instrumentation. Some of the new research vessels built and commissioned for survey during the expedition had better winches and echo-sounders and far more accurate navigational instruments; a satellite navigation system was available to the Atlantis II of the Woods Hole Oceanographic Institution. Narrow-beam precision echo-sounders, magnetometers and gravimeters were also made available on most of the oceanographic vessels. Going through the literature and the excellent atlases to assess the results is a long but exciting task. Many interesting findings are briefly mentioned in the following account.

Geology and geophysics:

The major discoveries relate to the complexity of the mid-Indian Ocean ridges and the famous triple junction, like an inverted Y, found south of the Seychelles, where the southern end of the Carlsberg Ridge (sometimes called the Mid-Indian Ocean Ridge) meets the Southwest Indian Ocean Ridge and the Southeast Indian Ocean Ridge which extend eventually into the mid-Atlantic Ridge and the South Australian Ridge, respectively (Fig.2). Until recently, geologists had no clear proof of the theory of continental drift first proposed by Wegener in 1910. However, in 1959, coinciding with the IIOE, Ewing, with Heezen and Tharp, published a paper describing a mid-ocean ridge running continuously in all the three major oceans for a total distance of 60,000km, 30-400 km wide and rising to 3000- 5000m above the ocean floor. The significance of these long ridges was realized when several ships all made successful and successive cruises to study the geological and geophysical aspects of the mid-Indian Ocean ridges. They were: the USSR's Vityaz in 1960-62 and 1964-65, the UK's HMS Owen and Dalrymple in 1961 and 1963, and the RRS Discovery in 1963, the USA's RV Argo and RV Horizon in 1960-64, as well as the RV Vema, RV Chain, the Conrad and the Pioneer, and Germany's Meteor.

The results indicated that these ridges are the site of basaltic upwelling and sea-floor spreading to form the new ocean floors. This phenomenon is now called plate tectonics. Also discovered was the 90°- East Ridge in the eastern part of the Indian Ocean. This straight ridge rises out of the Bay of Bengal sediments, about 1000 km north of the equator and extends in a straight line for 4000 km to the south; its crests lie 1800-3000 m below the ocean's surface. This ridge is unconnected with other ridges and is aseismic; its origin is an enigma.

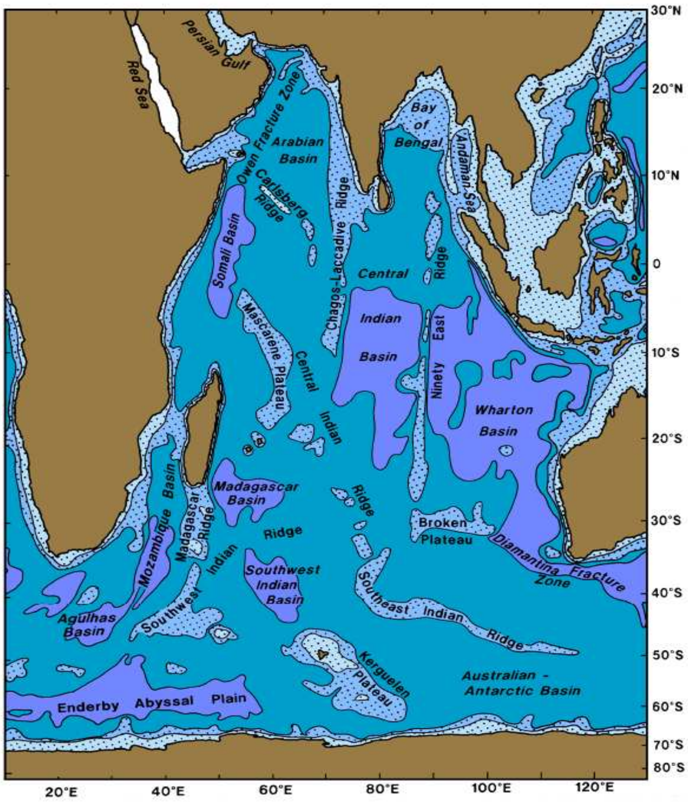


Fig.2.3. Sea floor of Indian Ocean

The hot holes in the Red Sea were another surprising discovery of the IIOE. Although the Dana and the Atlantis had reported finding some unusually warm waters in the bottom of the Red Sea during their cruises in 1947 and 1958, little did they expect that what they had passed over was really a rich mineral source at the bottom of the sea. *To quote Swallow* in one of the issues of Oceanus: 'We were expecting something unusual on Discovery Station 5580 on September 11, 1964. It was near 21°N in the middle of the Red Sea, very close to the place where both the Atlantis in 1958 and the Atlantis II in 1963 had found abnormally hot salty water near the bottom. We had anchored a radar buoy in water about 2200 metres deep, and were putting down a closely-spaced cast of water bottles. Approaching the bottom, the one-second pinger on the wire below the bottles had gone out of step and then re-synchronized itself with the echo-sounder - a sure sign (with that particular pinger) that it had gone through a sudden change of temperature. But even then we found it hard to believe the thermometers when the bottles came up. All quite normal, around 22° C to within 200 meters of the bottom, then 26° C then both thermometers went off scale (over 35° C), then again both protected thermometers went off scale but the unprotected thermometer showing 58° C. And so on. We did a second dip using only 60° unprotected thermometers on the deeper bottles - the only means we had of measuring the high temperature of the bottom water, which we found after correction to be about 44.3°C. This was far in excess of the 25.8°C found previously and which in itself had seemed abnormally high. Then the salinity turned out to be equally surprising. When water was being drawn from bottles that had been near the bottom, it seemed to run out more slowly than usual, and salinity at these holes was estimated to be extremely high, measuring about 270 parts per thousand, while the normal salinity of the Red Sea water varies between 38-40 parts per thousand. The origin of these warm-water and high salinity holes was traced to the Great Rift Valley which originates in East Africa and extends through the Red Sea and Gulf of Aden, since all this is an area of intense sea-floor spreading and the birth of an embryonic ocean. The overlain sediments in these hot holes were estimated to contain a high percentage of iron, manganese, zinc and copper. A Sudanese-Saudi joint commission, in collaboration with Germany, was looking for the possibility of exploiting these sediments for these metals.

Physical oceanography and meteorology:

The scientists were astounded to see the see-saw game played by the monsoon winds with the surface currents. During the strong southwest monsoon season, the Somali current was raging towards the north and then northeast near 8°- 10°N. The current was strong, up to 7 knots (~3.6m/s), and its inner edge was close to the Somali shore, where the temperature of the, surface waters was sometimes I6°C or less when the rest of the Arabian Sea was at nearly 30°C (Fig.2.4). It was also noticed that a strong set of the Somali current preceded the onset of the southwest monsoon along the west coast of India by almost a month, thereby indicating a possible relationship between the two events. Meteorologists and physical oceanographers now descended on the East African coast with many ships to study and unravel the Somali events vis-à-vis the Indian monsoons.

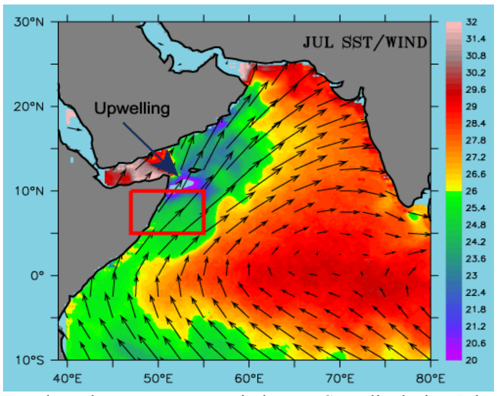


Fig.2.4. SST and southwest monsoon winds over Somalia during July. The red rectangle shows the Somalia current and the blue shading is the area of strong upwelling

Biology and chemistry:

The biologists were quite anxious to learn what sustainable yield of fish the Indian Ocean could provide and what were the productivity estimates and their translation into biological resources. Here again, the ship surveys covered upwelling regions and reported highest productivity rates in the Arabian Sea and off the northwest coast of Australia. However, no new fishing grounds were discovered, but the biological surveys indicated areas for further detailed study. As a result, the Food and Agricultural Organization of the United Nations (FAO) constituted an Indian Ocean Fisheries Commission to help assess the fishery potential of the Indian Ocean. At first sight, the massive Somali upwelling area appeared to promise rich fishing grounds, as is the case with other boundary currents elsewhere, as the Benguela, Peru and California currents, but it would appear that the high productivity recorded off the Somali and Saudi Arabian coasts failed to reach massive production at the tertiary level: in practice, fish. Why? The chemical oceanographers did not have much to say about the nutrient distribution in the Indian Ocean, as compared to other oceans. A chemical front was recognized around 10°-20°S through which an increase in the nutrient content of the waters took place as one proceeded towards the northern Indian Ocean. Another important feature noticed was the existence of an oxygen-deficient layer (between 200 and 800m depth), in the Bay of Bengal and Arabian Sea, for which a convincing explanation is still to be found. In some places in the Arabian Sea, even the presence of hydrogen sulphide was recorded. It would appear that the development and persistence of an oxygen-minimum layer in large parts of the Bay of Bengal and the Arabian Sea is a curse on the northern Indian Ocean's productivity.

Thus the International Indian Ocean Expedition (1959-1965) marks a watershed in the pursuit of knowledge of the Indian Ocean. The main results, briefly described above, further attracted the attention of scientists the world over to begin more detailed studies of selected areas, such as the Somali current, the mid-Indian Ocean ridges, the effects of monsoonal winds on surface currents, the productivity of the upwelling areas, geochemistry and geophysics etc.

NATIONAL INSTITUTE OF OCEANOGRAPHY (INDIA):

This is the first ocean research center in India and was established in 1966 under the Council of scientific & Industrial Research (Govt.of India). It is located at Dona Paula, about 7 km away from Panaji, the capital of Goa state. It has three regional centers, one each at Cochin (Kochi), Mumbai and Waltair. While Kochi regional center started working from 1962, Mumbai and Waltair are working from 1975 and 1976 respectively. At present the staff strength is over 500.

The research work of the Institute is carried out by seven Divisions viz., Physical, chemical, geological and Biological Oceanography, Instrumentation, Ocean engineering and planning & Data division.

The aims and objectives of the institute are to develop adequate knowledge related to physical, chemical, biological, geological, geophysical and engineering aspects of the seas around India. To build up competence in using the sea for the benefit of the people of the country, it included exploitation of living resources of the sea, sea farming technology, deep sea exploration of minerals, drugs from marine plants and animals, utilization of energy from the sea, development of offshore oilfields, coastal zone and harbor development and studies of effective control of pollution. Apart from this self sufficiency in marine instrumentation and data dissemination mechanism for user communities also has been included. All these divisions are working with sponsored research projects of various government and non governmental organizations.

The first research vessel of the country, R.V.Gaveshini was commissioned in January 1976. The ship was well equipped with sophisticated equipment for all disciplines of oceanography. The vessel had the capacity of accommodating onboard 19 scientists and 45 ship officers and the crew. It has four laboratories covering an area of 134 m^2. Till 1981 it had spent 941 days at sea in 100 cruizes covering more than 3500 stations along 1,40,000 line kilometers. After wards most advanced modern vessel O.R.V.sagar Kanya was procured.

Fig.2.4 The RV Gaveshani

The RV Gaveshani, was NIO's first research vessel acquired in December 1975. In her 19 years of service (until 1994), she completed 246 cruises, the last being off the east coast, before she went into dry dock in July 1994. She accidentally caught fire on 26 August 1994 during refit and modernization. She was then declared unserviceable in December, 1995. The ORVSagar kanya, was a deep-Sea Research vessel, owned by the Department of Ocean Development, Government of India. This was built at Federal Republic of Germany in 1983. NIO is a major user of this vessel for its data collection. This 100.34m long, 4209 ton, all weather multi-disciplinary vessel enhanced Institute's capabilities. It is fully air-conditioned with 13 laboratories on board spread over 3 decks having an endurance of 45 days providing accommodation to a total of 91 staff including 32 scientists. In 1990 a multibeam swath bathymetric survey system was also installed. The system enables coverage of a large area as much as twice the depth and can produce real time graphic display of cross profile, bottom map and can also produce on a printer bottom bathymetric chart. The RV Sagar Shukti is a coastal research vessel, converted by acquiring a fishing trawler by M/s Hooghly Dock & Port Engineers Limited (HDPEL), Howrah, West Bengal, India and owned by NIO.

Fig.2.5. ORV Sagar Kanya

Fig. 2.6 RV Sagar Shukti

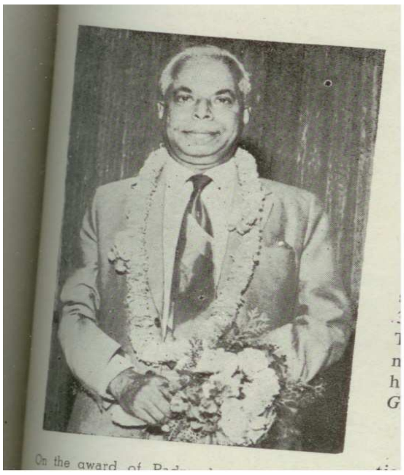
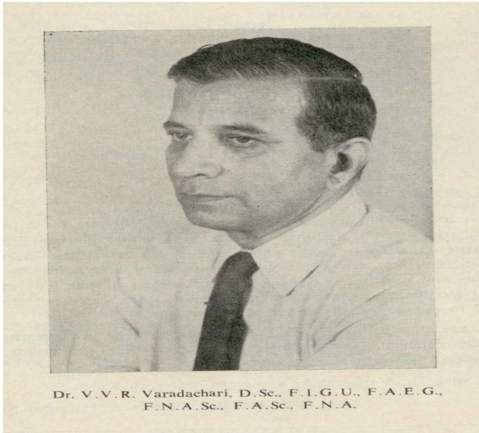


Fig.2.7 Dr.N.K.Panikar,First Director of NIO ,



Dr. V. V. R. Varadachari, D.Sc., F.I.G.U., F.A.E.G., F.N.A.Sc., F.A.Sc., F.N.A.

Fig.2.8 Dr.V.V.R.Varadachari,the Second Director of NIO

Table 2.3.IIOE Participants, ship time, estimated cost (U.S$) (From UNESCO 1963)

1. **Countries participating:**

   (a) Ship-operating countries: Australia, France, Germany (Fed. Rep.). India, Indonesia, Japan, Pakistan, Portugal, Republic of South Africa, Thailand, USSR, UK, USA.

   (b) Other participants: Burma, Ceylon, China, Pthiopia, Israel, Italy, Malagasy Republic, Federation of Malaya, Mauritius, Sudan.

   Number of ship-months: 323 (approximately)

   Distribution: Australia (37), France (20), Germany (Fed. Rep) ((>), India (24), Indonesia (3), Japan (2C), Pakistan (18), Portugal (3), Republic of South Africa (13), Thailand (2), USSR (20), UK (35) and the USA **(119).**

2. **Area of study:** Indian Ocean including adjacent seas.

3. **Period of study:** 1959 to 1963, peak at 1962, 1963 and 1964.

4. **Object of study:** Complete survey of the Indian Ocean, including descriptive physical, chemical, biological oceanography, marine geologv, geophysics and meteorology.

5. **Co-ordinator:** The Secretary, IOC

6. **Principal sponsors:** UNESCO, SCOR and IOC

7. **Other interested organizations:** International Meteorological Centres, Indian Ocean Biological Centre, FAO, WMO.

8. **Estimated costs** (US$):

(a) Cost of approximately 16 ships each operating in the Indian Ocean for 8 months	2,400,000
(b) Training of 25 scientists from Indian Ocean area, each for one year @ $3,000 per head	75,300
(c) Special equipment for each ship @' $24,000 per ship	384,000
(d) Salaries of the scientists working on ships (100 people for 1 year)	550,000
(e) Working up the scientific results (100 people for 1 year)	600,000
(I) Publication of results	30,000
(g) TOTAL COST	4,039,030
Less estimated contribution from normal operating costs and salaries	2,000,000
Estimated extraordinary cost	2,039,000

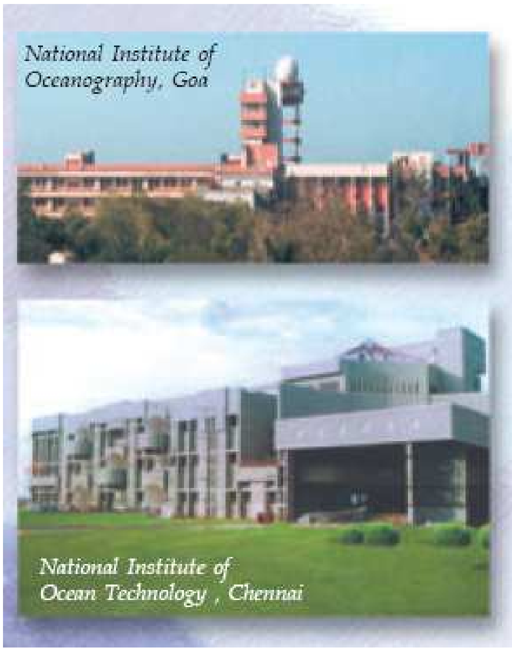


Fig.2.9.NIO & NIOT Buildings

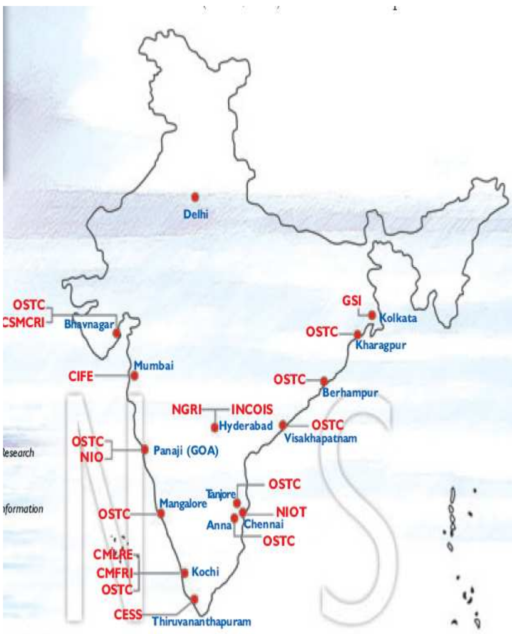


Fig.2.10.OSTCs in India

Recently Department of Ocean development (DOD) under the Ministry of Earth Sciences, Govt. of India started several OSTCs (Ocean science technology cells) as shown in Fig.2.10, NIOT (National Institute of Ocean technology)(Fig.2.9), ICMAM (Integrated Coastal and Marine Area Management) and another separate center for Antarctic studies called NCAR (Natrional Center for Antarctic & Ocean Research) was created. Apart from these directly related centers there are many organizations and universities are either directly or indirectly related to ocean research in India. Another important organization worth mentioned here is India Meteorological Department (IMD).Some of the places where ocean research is going on is as shown in the map. Center for Earth Science studies (CESS) of Government of Kerala is also involved in coastal protection studies. Orissa government started CDA (Chilaka Development Authority) and ORSAC (Orissa Remote Sensing Applications Center) for the studies of Chilaka and other coastal areas of Orissa.

Subsequent to IIOE, many international small scale expeditions were conducted both in the Arabian Sea and bay of Bengal to address monsoon related investigations like ISMEX-77, MONEX-77, MONEX-79 etc. the NIO,Goa initiated later initiated several oceanographic cruises on its own using RV Gaveshini and ORV Sagar kanya and established the oceanographic data base at the institute. The coastal as well as open sea hydrography, circulation, water mass structure and upper ocean thermodynamics in the Arabian Sea and Bay of Bengal have been addressed in detail. Subsequent to the above expeditions, monsoon experiments in the northern Bay of Bengal (MONTBLEX-90 and BOBMEX-99) and the Arabian Sea (Indian JGOFS) were successfully conducted. The results of MONTBLEX -90 (Monsoon Trough Boundary Layer Experiment) in the northern Bay of Bengal highlighted the importance of stratification and horizontal advection of heat for the cyclogenesis and sustenance of monsoon depressions.

After IIOE, India and erstwhile Soviet Union conducted two Indo-Soviet Monsoon Experiments (ISMEX) in 1973 and 1977 respectively during which vast amount of meteorological and oceanographic data were collected from the northwestern Indian Ocean including the Arabian Sea. The next intensive study was the Indian Ocean Experiment (INDEX) during the First GARP Global Experiment (FGGE), which investigated the summer monsoon response of the Somali Current. Subsequently, during the International Monsoon Experiment (MONEX) in 1979, Russian Vessels along with the Indian research vessel 'Gaveshini' collected data on currents and hydrography at selected stations in the Indian Ocean. In the following decade, only a few bilateral or individual studies were carried out in the Indian Ocean. These included the studies of Somali current regime (Swallow et al., 1991; Schott et al., 1986, 1990) regional studies of Indian coastal currents (Shetye et al., 1990, 1991a) and the West Australian boundary circulation (Smith et al., 1991). Considerable additional data were also obtained from Expendable Bathy Thermograph (XBT) surveys from volunteer ships, GEOSAT satellite altimetry and surface drifter studies (Molinary et al., 1990). The next intensive survey of the Indian Ocean was conducted during the World Ocean Circulation Experiment (WOCE), in 1995 – 1996. During the WOCE period, good quality data sets on hydrographic properties and various tracers were obtained. In addition, deep float and surface drifter deployments, moored arrays, repeat XBT schemes and high precision TOPEX/POSEIDON(T/P) altimetry operational since 1993, provided new insights into the variability of circulation in the Indian Ocean and its relations to forcing fields. In the northern Arabian Sea, large observational programmes with in the contexts of the Joint Global Ocean Flux Study (JGOFS) were carried out during 1994-1996. Recently, Indian Ocean Experiment (INDOEX in 1998 and Bay of Bengal Monsoon Experiment (BOBMEX) in 1999, Arabian Sea Monsoon Experiment (ARMEX) in 2002 were carried out which concentrated on oceanic as well as atmospheric parameters over the Indian Ocean.

India started expeditions to Antarctica also from 1982 onwards. It established a permanent research station at Antarctica called ‘Dakshin Gangotri’. Every year scientists go there in December and conduct researches.